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Evaluating the Use of a Carbon Footprint Calculator

Communicating Impacts of Consumption at Household Level and Exploring Mitigation Options

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Supporting information is available on the *JIE* Web site

Summary

Through an increasingly globalized supply chain, local consumption of goods and services has impacts around the world. The carbon footprint can be used to link local consumption to global greenhouse gas emissions. This study describes the development and use of REAP Petite, a household-level footprint calculator. We describe how the tool integrates geodemographic information with user-inputted data; allows users to compare their footprint with others in their community; and presents them with targeted pledges to help them reduce their impact. Such tools can help individuals to see the impact their consumption has on emissions and help promote alternative behaviors. Based on the lessons learned during tool development and through using the tool with individuals in the UK and Sweden, we make recommendations for the development of new footprinting tools for use in the public domain. We highlight the benefits of using bottom-up methods for calculating footprints; recommend that designers consider future-proofing their tools; discuss the trade-off between complexity and usability; and recommend that designers consider going "beyond carbon" to increase the appeal of tools to a wider audience. We also highlight the importance of providing opportunity for users to compare their footprints with those of others and of monitoring and evaluating user engagement with the tool.

Introduction

Consumption-based modeling and accounting has improved markedly in recent years, with the development of more finely detailed models, creation of time series, application of varying environmental extensions (cf. Dietzenbacher et al. 2013; Lenzen et al. 2013; Peters et al. 2011; Tukker et al. 2013), and development of interactive portals for data exploration (Lenzen et al. 2014; Roelich et al. 2014). Underlying these developments is a need to better understand, and communicate, the impact that end-use consumption has on the wider natural and/or social environment in order to promote policy and behavioral change. Without a mechanism to promote such change, outputs from consumption-based approaches, though interesting, will do little to mitigate the environmental and social problems that are driven by unsustainable consumption and production. When developing new approaches and new data, it is important to consider how this information is presented, and whether it is useful, to final consumers. One way of engaging with final consumers is through footprint calculators: tools for individuals to explore the impacts of their consumption. This article presents lessons learned from the development and application of a household-level carbon footprint (CF) calculator that embeds global emissions within a local context of behavioral change.

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From Global to Local Consumption-based Emissions

Consumption-based Accounting

National emissions inventories usually take a production perspective: only capturing emissions emitted within the territory through industrial and household activity. This territorial-based allocation is the reporting method required by the United Nations (UN) Framework Convention on Climate Change and follows the guidelines from the Intergovernmental Panel on Climate Change (IPCC) (Barrett et al. 2013). Territorial emissions are a common focal point within political processes, such as climate negotiations, but these accounts are detached from the driving forces behind the production of materials that cause these emissions. Consumption-based emissions, in contrast, relate directly to the goods and services that end users are familiar with, and are therefore particularly suitable for engaging individuals with climate change. A consumption-based emissions account is often referred to as a CF (Wiedmann and Minx 2008). Consumption-based accounting (CBA) can measure the impact of products consumed by domestic populations, taking into account emissions occurring throughout the product's global supply chain. CBA is gaining policy relevance as nations consider their role in global emissions reduction, and some government authorities are now reporting consumption-based emissions on an annual basis (e.g., UK and Sweden).

An increasing demand for CBA approaches is being supported by rising data availability. Historically, methods and data to compile accurate consumption-based emissions accounts have not always been readily available. However, with the introduction of resource efficiency policies (e.g., Europe 2020 [EC 2010]), there is a need to establish comprehensive, multiregional data sets to allow consumption-based emissions accounts to be compiled. Many countries are now required to produce annual consistent systems of national accounts to calculate gross domestic product (GDP). For example, European Union (EU) member states are required to produce standardized 60-sector supply and use tables on an annual basis (Tukker et al. 2009). Consequently, a number of multiregional input-output (MRIO) models and data sets are now available for consumption-based studies (see Tukker and Dietzenbacher [2013] for an overview). Further, technological advances mean that these data are now entering the public domain and being presented by online interactive platforms (Roelich et al. 2014; Lenzen et al. 2014).

Downscaling data to an appropriate level is needed to make this information accessible and relevant to members of the public. Most MRIO data sets are based on country or regional scales, allowing differences to be seen between consumption and production profiles (and associated emissions intensities) at the national level, but subnational differences are not apparent. Disaggregating national-level footprints to local levels is relatively straightforward and relies on data about the expenditure profiles of end users at the scale of interest (Baiocchi et al. 2010; Feng et al. 2010; Minx et al. 2013; Hubacek et al. 2014). Such data are available through national statistics offices expenditure surveys, or through agencies responsible for data management of credit/store card data. These data represent the *average* expenditure profile of a household belonging to a particular income decile or geodemographic profile. At the household level, differences in consumption arise from varying obligations and responsibilities, culture and personalities, personal financial situations, and so on, and information about these differences can be gained through surveys of individuals. By disaggregating national data to local levels, tools can be produced that represent consumption-based emissions that are relevant to small scales (i.e., to individuals, households, or communities). However, having the technical capability is only the starting point of bottom-up engagement with final consumers to promote more sustainable consumption patterns.

Community Engagement with Carbon Emissions

Top-down approaches to reducing carbon emissions have been shown to be inadequate, partly owing to lack of international agreements (Van Aalst et al. 2008). In the UK, approximately 60% of territorial emissions result from actions taken by households, linked to their consumption of food and other goods, energy, and personal travel (Defra 2014a), and recreation and leisure account for over one quarter of household emissions (Druckman and Jackson 2009; data from 2004). Individuals taking steps to reduce their emissions have the potential to move society a significant way toward commitments such as the EU's 40% greenhouse gas reduction target by 2030 (EC 2014). Further, because consumer purchases drive the production of goods and services overseas, because of the international nature of their supply chains, changing consumer behavior has the potential to reduce emissions that occur outside national boundaries.

Government-led carbon reduction schemes (e.g., the UK's *Act on* CO_2 campaign) tend to focus on providing people with information about climate change, which is important because studies have shown that the public holds many misconceptions about the causes (see Lorenzoni et al. 2007). Whitmarsh (2009b) found that very few people mentioned domestic energy consumption or personal actions as causes of climate change, instead focusing on industry and governments. If individuals are expected to voluntarily reduce their carbon emissions, then they need to be supported to understand the causes and consequences of climate change (Whitmarsh et al. 2011). However, information provision schemes tend to result in slow rates of engagement (Kellett 2007) and have not been particularly effective in reducing emissions (Lorenzoni et al. 2007). This may be because they are based on the information-deficit model of public engagement, which assumes that people behave badly toward the environment because they do not know any better. A large body of research (e.g., Kollmuss and Agyeman 2002; McKenzie-Mohr and Smith 1999; Owens and Driffill 2008) has emerged to counter this model, describing many factors other than knowledge that influence behavior.

Given that mechanisms of "engagement," which rely solely on information provision, do not tend to be very effective, there is growing interest in more participatory methods where people are supported to explore the issues for themselves, which may increase the chances of behavioral change occurring (see Haq et al. 2008, 2013). These approaches, often led by grassroots organizations or individuals, can be effective for encouraging shifts toward more sustainable behaviors and reducing emissions (for examples, see Center for Sustainable Energy 2009; Hope and Alexander 2008; Middlemiss 2011), and there is a growing interest from practitioners, policy makers, and academics in the role that communities can play in enacting change (Middlemiss and Parrish 2010). However, it can be difficult for such initiatives to scale up or be replicated (Seyfang 2010; M. Peters et al. 2010), and further research is needed into the mechanisms by which any behavioral changes occur (Middlemiss 2011).

Using individual CF calculators can be an effective method for engaging individuals at the community level, to help illuminate the contribution that individuals make to emissions, which is important because the public typically underestimates their contribution. By allowing people to compare their footprints to those of others, it may induce a feeling of moral obligation to change, which, along with community activities (e.g., Mulugetta et al. 2010; Heiskanen et al. 2010), has been shown to be a powerful determinant of action (Whitmarsh 2009a). Asking people to pledge to change aspects of their behavior can be effective for inducing change (McKenzie-Mohr and Smith 1999; Lokhorst et al. 2011).

Turner (2014) divides CF calculators into first and second generation. First-generation CF calculators focus on emissions from direct energy use: mainly household energy use and personal car and air travel (Padgett et al. 2008). Turner (2014) critiqued such calculators for reducing climate change to an energy problem and making people feel that there is a limit to what they can do to reduce emissions. Second-generation tools shifted toward a more holistic CBA approach. These newer tools may encourage users to think about lifestyle shifts other than energy consumption, and may help to highlight actions they can take as individuals, rather than expecting industry or governments to make all the changes.

Awareness of the concept of CFs and use of calculators is growing, but is not yet widespread (Whitmarsh et al. 2011), although there are many available (see Padgett et al. [2008] for a review of U.S.-based online calculators). In 2011, the Stockholm Environment Institute developed an online, free-to-use, household-level CF tool, REAP (Resources and Energy Analysis Program) Petite (www.reap-petite.com), which has been used in a number of community projects. This tool differs from others in three main ways: it uses geodemographic information to estimate users' likely impact and allows them to modify this based on their lifestyle; it allows users to compare their footprint with others in their communities; and it presents users with targeted pledges to help them reduce their impact.

In the following section, we give an overview of the methods and data used within the tool and then discuss how the tool has been used with a community in Yorkshire (UK) and Stockholm (Sweden). These case studies are used to discuss the lessons learned during tool development and user engagement with the tool. The Swedish version of the tool (http://minklimatpaverkan.se/) was developed in 2013 and slightly differs cosmetically and in terms of the footprint calculation methods owing to data availability and housing environment in Sweden. For brevity, the following methods summary is based on the UK version. More detail of tool methods and differences between the tools are detailed in the Supporting Information available on the Journal's website. The user experience is similar for each version, and lessons learned are presented from experience of using the tool in both countries.

Method of Footprint Calculation

As described in Gao and colleagues (2014), CF analyses may be broadly divided into those covering emissions owing to personal-, product-, organizational-, city-, and country-level activities. Standards have been developed, particularly for organizational and product-level footprinting (see Gao et al. 2014). However, because of the need to specify individual functional units and draw boundaries around supply chains and/or use phases within these applications, the methods covered by these standards (e.g., process–life cycle assessment [LCA]) are not relevant for application within personal footprinting tools, which are designed to be used by individuals across a wider population. Analysis of all the products that an individual consumes or uses may, theoretically, be possible using standardized process-LCA methods, but this would be a time-consuming process, which could not be efficiently replicated across a population. By downscaling national CBA information to the individual level, at the population scale, results are consistent with national statistics and comply with best practice in relation to CBA.

REAP Petite calculates CFs in a manner consistent with the methodology used to calculate the UK's CBA. The footprint includes both direct emissions from fuel burning activities and the full supply-chain (indirect) emissions from final demand purchases of goods and services. REAP Petite takes the estimate of the disaggregated neighborhood footprint and adjusts to correct for individual circumstances using survey-based data. Data from a number of sources are used to calculate a household's CF (see figure 1 and supporting information on the Web). Compared to top-down methods of calculating local footprints (such as Baiocchi et al. 2010; Feng et al. 2010; Minx et al. 2013; Hubacek et al. 2014), REAP Petite uses bottom-up data to ground-truth household impacts (see figure 1, gray box). REAP Petite calculates individual impacts in a unique way: It incorporates top-down geodemographic data from Mosaic (see figure 1, black box) to better estimate the household footprint before allowing users to refine their predicted impact.

Calculating Product Conversion Factors

The REAP UKMRIO (UK MRIO) model is used to calculate national-level household and government consumption-based emissions (figure 1, box a) (see Wiedmann et al. [2010] for details of data sources and methodology behind this model). This method reports total UK footprints by product using 123 economic sectors based on Standard Industrial Classifications (SIC), which bear little resemblance to a typical household's

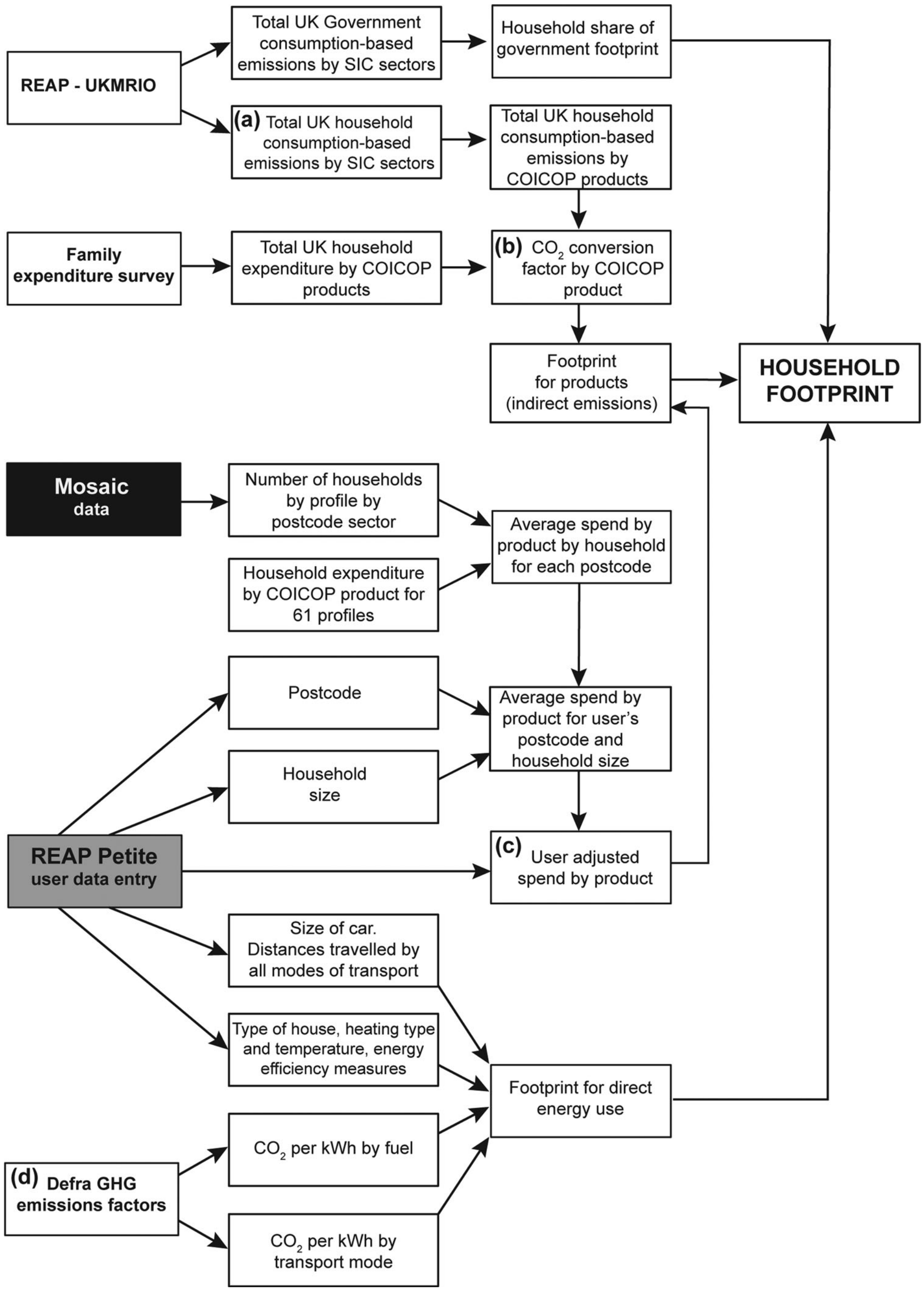

Figure 1 Data sources and methods used by REAP Petite to calculate household footprint.

shopping list. These sectors are mapped onto the Classification of Individual Consumption According to Purpose (COICOP) system (UN 2014), which has a more tangible set of products. The COICOP system is used in the Family Expenditure Survey (FES)/Living Costs and Food Survey (ONS 2007), which annually publishes the average household expenditure on every COICOP product group. By multiplying this spend by the number of households in the UK, the total spend by all households is found. This means that if the total household footprint by COICOP products is known, a conversion factor for each product can be generated (figure 1, box b). This conversion factor is multiplied by the user's reported spends to calculate their household footprint. Conversion factors could be taken from the MRIO itself, but as discussed, the SIC is not a useful classification for characterizing household spends and the conversion factors produced by an MRIO database require spends to be reported in basic prices. Users of the tool will want to report the actual price paid for a particular product. By dividing total product emissions by the spends from the FES/Living Costs and Food Survey, the conversion factor calculated takes

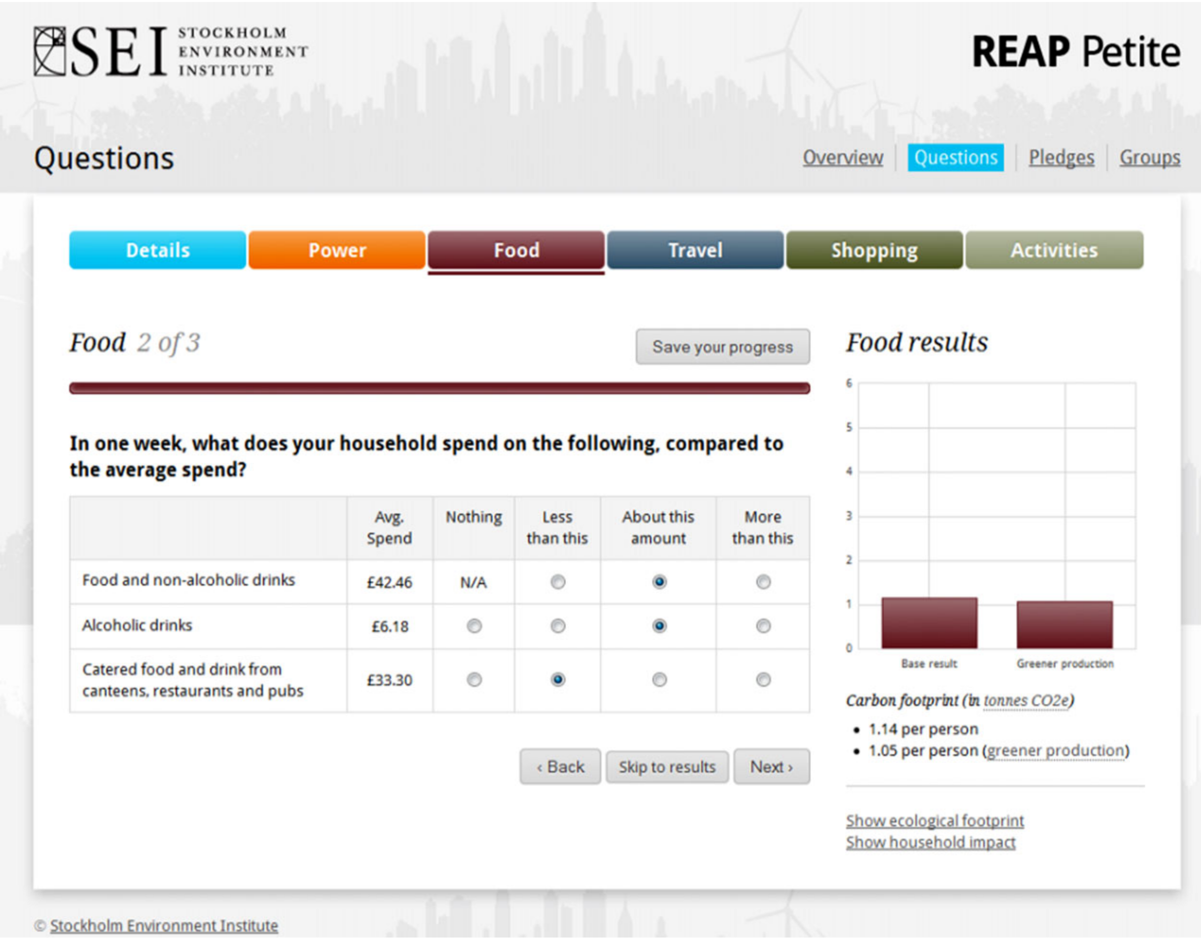

Figure 2 Image of the tool in use, during the "Food" section of the tool, where the user is completing a level selection type question.

into account taxes such as value-added tax. Using a monetary-based MRIO table, rather than a table using physical units, is problematic given that money is used as a proxy for the physical flow of goods. However, for this tool, we wanted the methods to be consistent with the reported UK CBA.

It could be argued that to calculate an accurate neighborhood footprint, an MRIO database with subnational data should be used that takes into account localized production information. However, the aim of this tool was to produce household footprints that could be compared relative to the national footprint, where differences were owing to different household behaviors rather than local production techniques.

Estimating Household Expenditure

REAP Petite uses the Mosaic geodemographic profiling data from Experian (Experian 2009) to calculate an average footprint for every postcode sector (around 2,500 households [Taylor et al. 2010]) in the UK. Experian determines 61 household expenditure profiles based on the COICOP classification. Given that the number of households of each type is known for each postcode sector, an average spend by product, by household can be calculated for every postcode. The user is presented with this figure to guide their expenditure level and they can adjust it according to their lifestyle (figure 1, box c). In order to minimize the time taken to complete the tool, some aspects of the footprint cannot be adjusted by the user and instead rely on UK average figures. These are used for items where there is little variation between households (e.g., postal services). The impact associated with government activities, such as national health services and road building, is shared equally across the population.

Impacts of Home Energy Use and Transport

Defra supplies conversion factors for calculating the emissions associated with heating, electricity used, and transportation (figure 1, box d) (available at Defra 2014b). REAP Petite users supply details of their fuel consumption from energy bills (if available), or these are estimated by the tool based on dwelling type, energy saving installations, and the presence of any on-site renewable generation. The Energy Savings Trust provides data on energy use by dwelling type and the typical percentage reduction in usage if different energy-saving measures are taken. For transportation, the user provides information on the distance traveled for noncommercial purposes by all forms of transport.

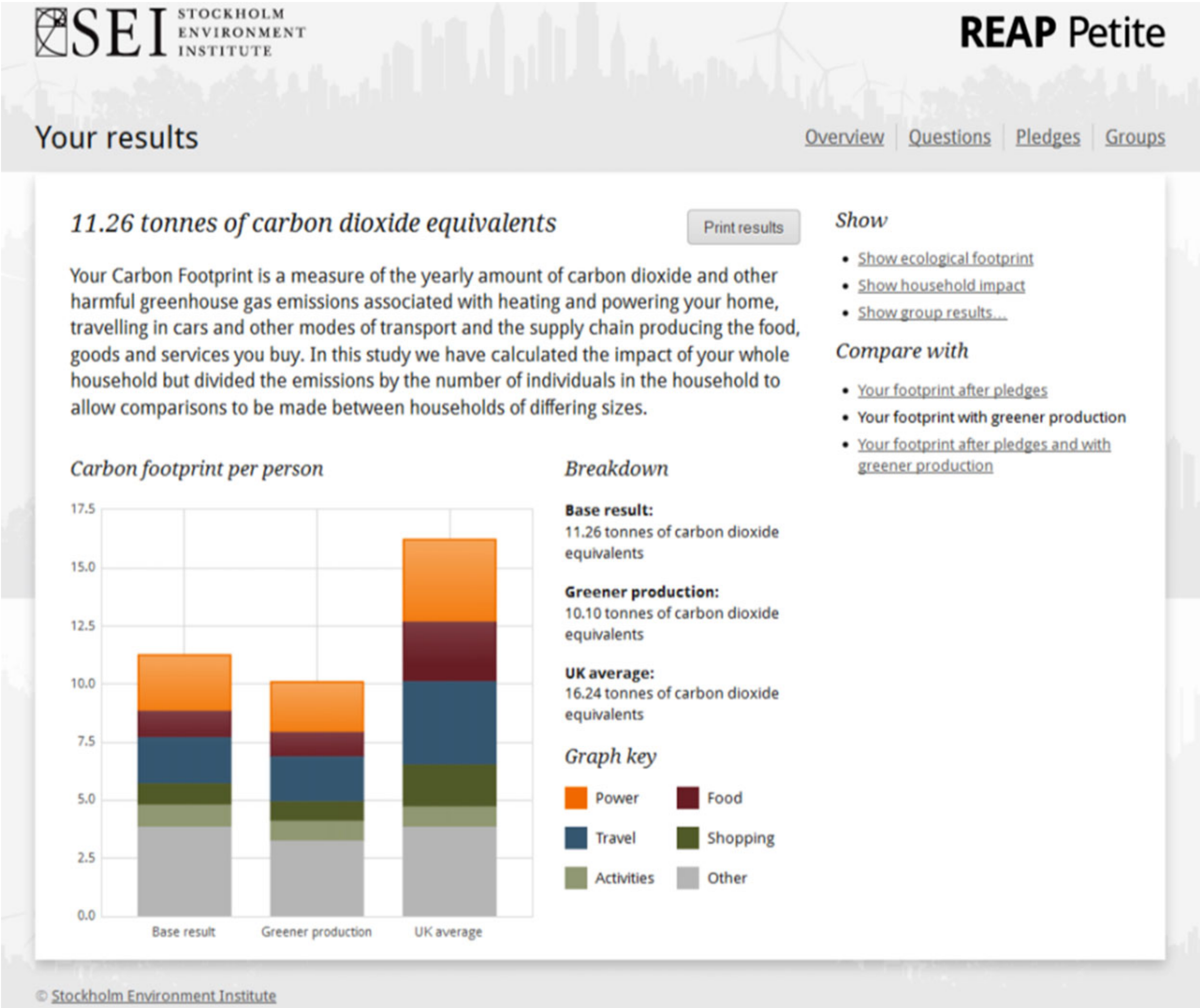

Figure 3 Image of the tool in use, during the "Your results" section of the tool.

Tool Design

REAP Petite was designed to have clear graphics and layout, sparse and simple text, and provide personalized information while being quick to complete: all features of successful carbon calculators highlighted by Coulter and colleagues (2008). The tool has six sections of questions: Details (personal information); Power; Food; Travel; Shopping; and Activities. During each question, users can see how their footprint varies with different responses, and at the end of the tool their household and individual footprint is compared to the national average.

The tool has three types of questions: data entry, level selection, and tick box. Examples of *data entry* questions are postcode and number of residents. Most questions are *level selection*, where the user clicks whether they spend more, less, or around the same as the estimate spend on a specific product (see figure 2). These are used because it is unlikely that users will know, for example, their households' annual spend on clothing, but by suggesting a monthly clothing spend by a similar-sized household in a similar area, users can easily compare their own habits. For example, the estimated monthly spend on clothing in a wealthy area of London is £55.72 compared to £20.96 in a less wealthy area of Manchester. Finally, *tick box* questions require the user to tick any options that apply to their lifestyle (e.g., presence or absence of solar panels). Colored bars at the top of each screen represent the different sections of the tool and give the user an indication of how far through the tool they are. The average time to complete the tool is 11 minutes, based on usage statistics.

On completion of the tool, users can see their complete footprint broken down into each section plus the "other" section, which includes the share of government impact (see figure 3). This is presented in a bar chart showing their footprint compared to the national average and under a scenario of greener production. For the greener production scenario, new product conversion factors are used that show the effect of 30% of electricity being sourced from renewables, which is in line with the UK's target for 2020 (DECC 2012). Users can also select whether they want to see their individual or household footprint and if the user is part of a "group" using the tool, they can compare their results to others in the group.

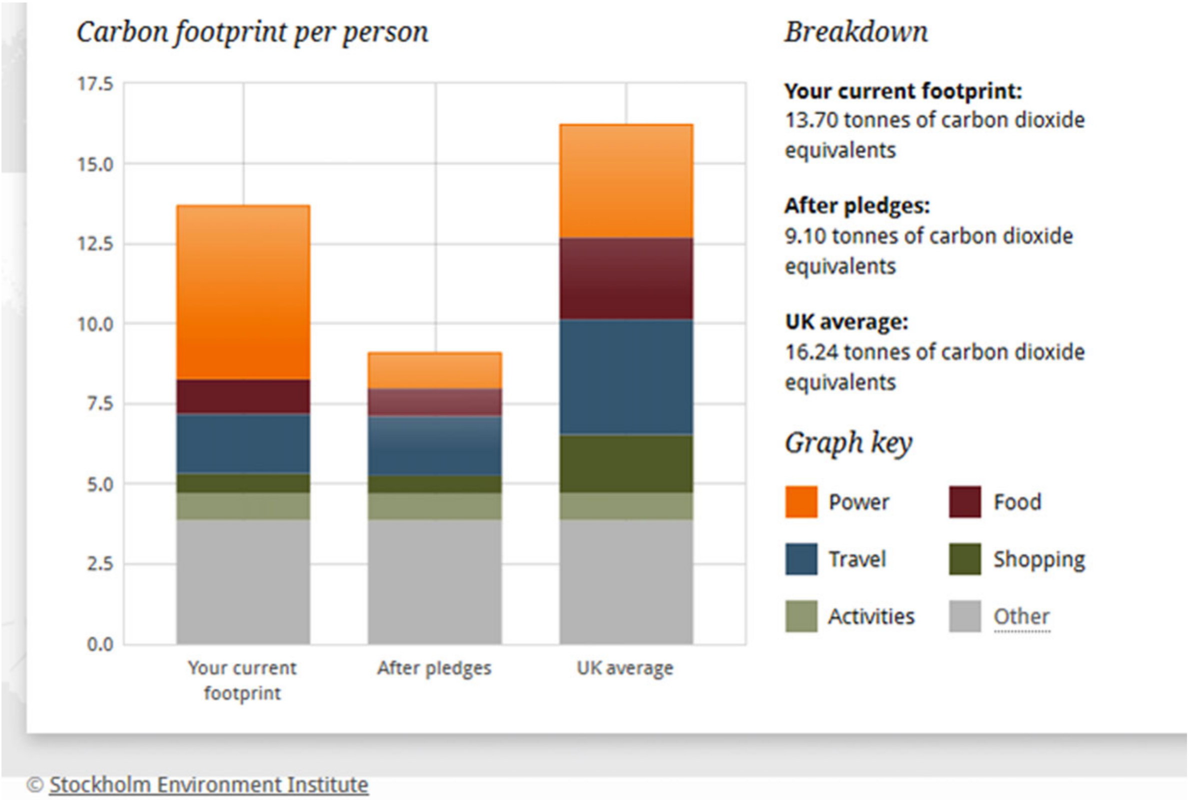

Figure 4 Image of the tool, showing the user how their footprint would be reduced if they achieved all their pledges.

The optional pledge section allows users to investigate the effect of a number of behavior changes on their overall impact (see figure 4). The tool uses data previously entered by the user to calculate the reduction potential of their household and tailors pledges to the user. For example, users can find out whether increasing the thickness of their loft insulation or installing double glazing gives the largest reduction to their footprint. Pledges cover all sections of the tool and are designed to cover different degrees of effort, for example, "Increase the proportion of locally produced food in my diet" and "Generate my own power using solar energy." For information about how the different pledges impact the footprint, see tables S1 to S5 and figure S2 in the supporting information on the Web.

Community-based Applications

The tool was designed to be used by individuals and community groups, and the Stockholm Environment Institute is currently involved in two projects using it to monitor the effectiveness of community-level interventions to lower carbon emissions.

In a city in Yorkshire, UK, a new housing estate has recently been built with sustainable features such as a communal biomass boiler, high levels of insulation, and interventions such as a car club and discount cycle purchase scheme. The estate managers want to know whether a household's footprint is lower than in their previous dwelling and whether they change over time. Residents are asked to complete REAP Petite when they first move into their new house, for their previous house, and then at yearly intervals. Advertisement of the tool was done through several means: a letter to each household including the Web address and a paper copy of the tool (with Freepost envelope), through the community Facebook page and Twitter stream, and the project team also knocked on people's doors and promoted the tool at community meetings. A prize draw with a value of £50 was used, which was one of the most effective methods for increasing responses. Providing residents with a paper copy of the questionnaire with Freepost envelope was also effective. Consequently, 28 of 64 households have completed the tool to date.

In Sweden, residents in the Stockholm suburb of Hökarängen were encouraged to use the tool at the beginning of a community project around sustainable lifestyles. This project is due to complete in summer 2015, when residents will be asked to complete the tool again. As in York, the tool was promoted in many ways, including through a community newsletter with a Web link and a door-knocking campaign to 3,000 homes where residents were given a postcard containing cartoon pictures with an environmental message and the tool Web address. The postcard was also distributed at a number of different community events and workshops. Information about the tool was also given at seminars/workshops, and 15-year-olds at a local school were tasked with completing the questionnaire together with their parents as part of their homework. So far,

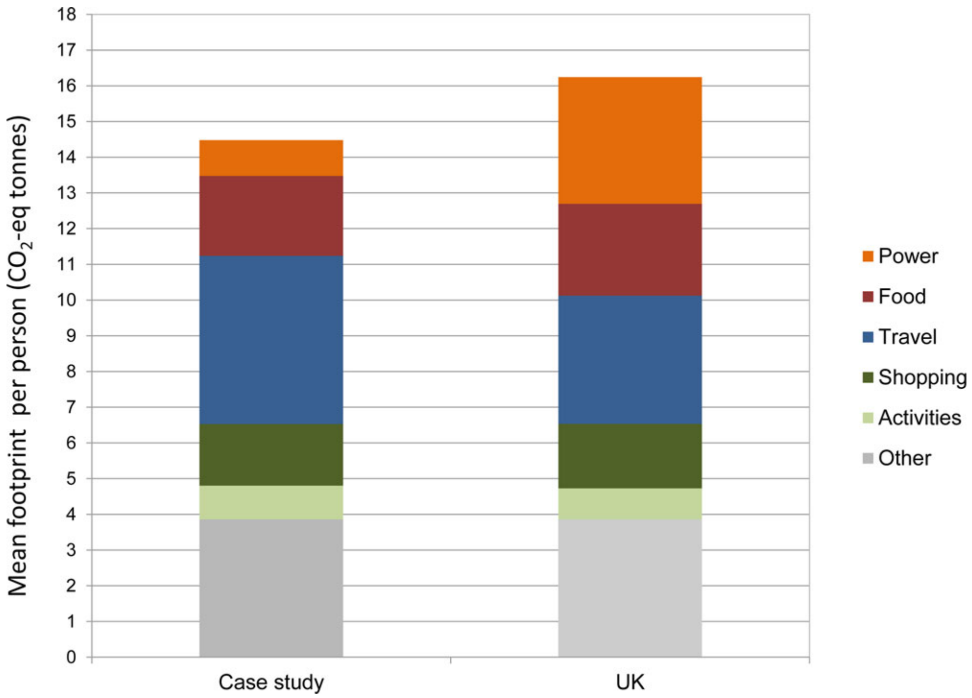

Figure 5 Graph produced for residents of the Yorkshire community, showing the mean footprint of respondents in the case study community compared to the UK mean.

Table 1 Total individual footprints of Yorkshire case study residents who completed REAP Petite more than once

Total footprint (tonnes CO_2-eq per person)				
Previous home	*Year 1*	*Year 2*	*Year 3*	*Notes*
21.14	24.95	21.34	45.94	Very high travel footprint
17.53			14.13	
15.79	11.39			
14.90	16.15			Relatively high food footprint
11.47	10.04			
16.77	16.25			Lower power offset by travel and shopping
13.79	14.01		13.04	Lower power offset by shopping
15.25	12.52			
10.53	8.35		8.83	
	14.30		16.70	Travel footprint increased
		27.15	16.11	Travel footprint decreased
	31.00		27.08	Very high travel footprint

Note: Shaded cells show the highest footprint for that individual.
CO_2-eq = carbon dioxide equivalent.

the Stockholm project has collected responses from around 75 households. In order to encourage users to update their profiles over time, all those who complete this will be entered into a lottery. It should be noted that respondents are not a representative group of the community given that they are biased toward people who have an existing interest in environmental issues or those who are motivated enough to use the tool after hearing about it.

Individual and group footprints have been communicated back to users in several ways. In the York project, a newsletter was produced for all residents of the area, which showed the mean footprint of those who had completed the tool compared to the UK average (see figure 5), indicating a significantly lower Power footprint but higher Travel footprint. The project team also attended residents meetings, which gave residents the opportunity to ask any questions about the process or the results, and met with some participants individually. This stimulated discussion about why sections of the footprint were particularly high or low. For example, one resident, when asked whether they thought living in the estate would help reduce their footprint, said that the house design had reduced their fossil fuel usage, but "*not by as much as I thought it was going to*" given that he was commuting large distances to work. Another resident was able to discuss the reduction in her food footprint owing to eating out less. Through these conversations, it became clear that the tool had helped residents think about their emissions in a very detailed way; for example, one resident said that their emissions associated with travel to shops was lower owing to "*online shopping, but someone has to drive it to me, so I'm not sure that has actually improved it*."

For the Yorkshire case study, we have been able to compare some residents' footprints over time. Table 1 shows both the large variation in footprints within this estate and how footprints compare to those of previous homes. Seven (of nine) residents saw a drop in their footprint after moving, whereas two (of three) residents who completed their footprint for their new home more than once showed a reduction in footprint.

Results from the Stockholm case study were also presented to residents in several ways. For example, during a workshop with one group of users (local sustainability ambassadors), results were presented and compared to Stockholm and Sweden averages (table 2). The group discussed why some had a higher/lower footprint in certain areas and what could be done to further reduce their environmental impact. Results were presented to local school pupils in a similar way, with discussion around the challenges involved in achieving sustainable consumption. Results for different groups and the community as a whole will be presented in a newsletter in late spring 2015, on the project's website and as part of a local public exhibition about the project.

As table 2 shows, the average footprint of the respondents in the Stockholm case study is substantially lower than the average citizen in both Stockholm and Sweden. There are likely to be several reasons for this. Average incomes are substantially lower in the Hökarängen community, the area mainly consists of apartments with centralized district heating, and there are good public transport options in the area and, consequently, lower car density. The impact from food consumption is substantially lower than the average for Stockholm and Sweden. This could be partly owing to the lower income levels, but also to the fact that a fairly high percentage of the respondents are vegetarian (17%) or eat vegetarian food to a large extent (8%). However, it should be noted that the respondents are not a representative group of the community because they mainly consist of people who have either joined the project activities with an interest in environmental issues or people who have been informed about the tool and are interested enough to use it.

Discussion and Recommendations

Community Engagement with Tools

Calculating footprints "is a complex yet imprecise science" (Kennedy et al. 2014, 536) because of data limitations and use of different inputs (see Padgett et al. [2008] for a discussion), but their use can help people to uncover the environmental impacts of their consumption. In particular, the use of pledges allows people to see their potential to make a difference to their footprint. The process of using a carbon calculator may help to counter the tendency reported by Whitmarsh (2009a, 2009b) of people underestimating their personal impacts on the environment. The question is: Will this help to change their behavior? It is important to reiterate that knowledge is only one aspect of behavior. Stern (2000) lists four influences on environmentally significant behavior: (1) attitudes, values, and beliefs; (2) contextual forces (social, economic, political, or institutional); (3) personal capabilities and resources (e.g., skills and knowledge); and (4) habit. REAP Petite mainly offers users an opportunity to gain new knowledge about their footprint, but the process of completing the tool has a potential to shift attitudes and change behaviors, too. This may be most likely when the tool is completed alongside peers where there is an opportunity for discussion of results. Further, by providing a list of pledges covering different aspects of behavior or purchasing decisions, the tool presents the user with options to reduce impact that can be ignored or selected depending on their economic situation. The tool therefore provides users with the ability to "customize" their response, so that action is more relevant to their particular situations and provides them with a real-time indication of how this may affect their emissions. There are parallels here with shifts in focus within corporate social responsibility schemes: In the past, reporting processes (such as, e.g., that used by the Global Reporting Initiative [GRI]) have been relatively prescriptive, instructing businesses on what they should provide information on. In recent years, there has been greater emphasis on the concept of "materiality": identifying and justifying key issues linked to core business. The argument is that these are more likely to be embedded within business activities and therefore more likely to lead to change (GRI 2014).

Studies have shown that people's willingness to change habits varies depending on what aspect of their lifestyle it impacts. People are most willing to recycle and conserve energy in the home, but there is resistance to changing travel habits (Lorenzoni et al. 2007). Druckman and colleagues (2011) used focus groups to explore the acceptability of different carbon reduction measures and found household energy reduction measures (such as temperature zoning and turning off appliances) to be acceptable, but compromising on hot water use and cooking were less acceptable. Changing diets to reduce emissions, particularly lowering red meat consumption, was also less popular. The pledge function in REAP Petite allows users to explore the effect of a particular lifestyle change. This may help to counter people's tendency to overestimate their contribution to mitigation (Whitmarsh 2009a), for example, to see that the use of energy-saving lightbulbs, which is being encouraged by EU policies and is a very popular energy efficiency measure for households, does not have a large impact on footprint (Parnell and Popovic Larsen 2005). The act of making a pledge may help to encourage people to enact that behavior change, although the psychological mechanism by which this occurs is unclear (Lokhorst et al. 2011).

Tool Development Recommendations

Here, we draw on lessons we have learned through the process of creating and using REAP Petite and make

Table 2 Footprints of Hökarängen case study residents compared to the Stockholm and Swedish average

Mean GHG footprint (tonnes CO_2-eq per person)	*Housing energy*	*Food*	*Transports*	*Other—shopping*	*Recreation/ culture*	*Mean total GHG footprint tonnes CO_2-eq/pp*
Sweden	2.21	2.00	1.96	1.82	0.76	8.8
Stockholm	2.12	2.62	1.83	2.60	1.05	10.2
Hökarängen respondents/pp (n = 75)	1.12	1.45	1.72	1.23	0.46	5.98
Seminar participants (n = 13)	1.26	1.42	2.18	1.20	0.57	6.64
Workshop participants sustainability ambassadors (n = 8)	0.94	0.95	1.69	1.28	0.50	5.11
School children (n = 16)	0.96	1.15	2.03	1.70	0.52	6.36

Note: GHG = greenhouse gas; CO_2-eq = carbon dioxide equivalent; CO_2-eq/pp = carbon dioxide equivalent per person.

recommendations for those wanting to design or use similar tools in the future. We begin by making recommendations about tool development and, in the next section, make recommendations about user engagement with tools.

Use Bottom-Up Footprinting Methods

The REAP Petite approach, of refining postcode-level expenditure estimates with a user questionnaire, provides finer geographic detail of neighborhood footprints. This technique allows analysts to determine whether particular household and communities have higher or lower emissions than predicted and to better target policies aimed at behavioral change. In addition, it helps users complete the tool by giving them an estimate of their expenditure to work from. This approach can also help encourage dialogue with other stakeholders: For example, in the Yorkshire project, results from residents are anonymized and fed back to estate managers who are using this information to explore why their travel is higher than average, despite the estate being located near cycle paths and regular bus services, and having restricted car parking on-site. This is an example of why generating this information in a "bottom-up" way, rather than downscaling a top-down model, is beneficial given that even within small communities key aspects of behavior can be uncovered.

Consider How Tools Can Be Future-Proofed

Tool designers should factor in the need for tool updates and consider the trade-offs between accuracy and results consistency. Many of the calculations within REAP Petite are a function of spend on a product and an emissions conversion factor. Over time, both product prices and the carbon efficiency with which they are made change and the calculation methods might be described as being out of date. In addition, obviously out-of-date questions (e.g., number of compact discs bought annually) might breed mistrust among tool users. However, if the tool is being used to study the effect of a policy intervention, consistency of data and questions is important to allow monitoring of the way households have altered their behavior and the effect this has had on their carbon dioxide impact. If data used to calculate the footprint have been updated, it may no longer be possible to determine whether a change in footprint is owing to a behavior change or a methodological change.

Consider the Trade-off between Complexity and Usability

The detailed nature of REAP Petite allows users to explore the effects of different aspects of their consumption on their footprint. However, this may dissuade people from using the tool, if they feel it asks too many questions, either because they think it is intrusive, for example, one potential user refused to complete the tool saying "*I've no idea why you would need to know about my alcohol consumption*," or because it is too time-consuming. Tool designers also need to consider how results are presented. For example, in REAP Petite, users can see how their footprint would reduce if the UK switched to a greener supply chain (see figure 3), but the Swedish version of REAP Petite omitted this detail because feedback from users suggested it was confusing.

In developing REAP Petite, we wanted people to be able to compare their footprints with those of others in their community or with the national average. Therefore, it was important that such comparisons were possible. Tool designers need to consider whether they are most concerned about detail and accuracy, or whether it is more important for them to be standardized, comparable, and accessible. Using downscaled national MRIO data sets to create footprint calculators has the advantage of allowing comparisons across geographies, and means we do not have to rely on more local data sets, which are rarely available.

Consider Going beyond Carbon

Tool designers may wish to consider whether "carbon" should be the sole indicator used or whether additional footprint measures would be useful. Other potential indicators include the embedded land use, water, or employment in the supply chains of goods and services. There is evidence to suggest that many people are "turned off" by messages about climate change and CFs, but may shift toward more positive behavior toward the environment if they think that their actions will help to create better societies (Bain et al. 2012).

One option could be to present a dashboard of indicators allowing people to minimize adverse impacts to aspects that are meaningful to them. Some people may be more concerned about equity and fair trade, whereas others may be motivated by environmental messages. However, if presenting such a dashboard, it is also important to consider whether the additional complexity may cause confusion for users and that, when presenting a range of indicators, the outcomes of consumption choices may lead to incompatibility in the most "sustainable" choices. For example, there may be conflict between promoting employment in developing countries and resource efficiency. In such cases, the use of a dashboard could help support the consumer to make informed choices based on their own priorities.

User Engagement Recommendations

Enable Comparison of Footprints

Individuals do not just act in self-interested ways: Behaviors are embedded within social contexts, and individual actions can be influenced by social norms (Jackson 2005) and sense of moral obligation (Whitmarsh 2009a). Calculators that allow people to compare their lifestyle and its impacts to others could help create this sense of citizenship (Whitmarsh et al. 2011). Creating a sense of competition within a group of users can also help induce behavior change (Jackson 2005). In both Yorkshire and Stockholm, participants were interested to see how their footprint compared both to others in their community and to the national average. These comparisons were also useful in discussions with those managing the Yorkshire housing estate. Stockholm participants found the opportunity to discuss and reflect on their footprints in a small group particularly useful.

Monitor and Evaluate Tool Use and Effects

We have tried to design a tool that is intuitive and allows users to explore their footprint and those of others in their community. When creating tools, it is important to consider the need for ongoing promotion of the tool and the effects of promotion efforts need to be monitored and evaluated. Asking simple questions such as who is using the tool, and how they found out about it, can be very useful for assessing the merits of different promotion methods. In both the Stockholm and York case studies, respondents appear to be biased toward those who are already aware of and interested in environmental issues. Any conclusions drawn from such respondents need to bear this bias in mind and consider that behavior of these individuals may not reflect behavior of the wider public.

Getting people to engage with the tool in the first place is an important challenge. In York, despite working with a group of people who had chosen to live in "greener" houses, and using numerous methods to promote the tool to participants, we only had around a 50% response rate. In both York and Stockholm, we boosted our responses by sending paper-based surveys to households. The disadvantage of this approach is that individuals are detached from their results and cannot immediately see the impact of any pledges on their footprint, which may reduce the ability of the tool to change behavior. There needs to be a better incentive to complete the online tool than "this will help you reduce your impact." One technique might be to highlight the money-saving incentives of a low footprint lifestyle. For example, many of the changes suggested in REAP Petite (such as reducing meat consumption or car sharing) are also associated with financial savings. Economic incentives can be important drivers for change, given that many people are motivated to shift toward environmentally responsible behavior for reasons other than wanting to protect the environment, for example, a desire to reduce energy costs (Seyfang 2010). However, as Sorrell and colleagues (2009) point out, any money saved might be spent on other potentially more carbon-intensive activities. When planning engagement activities, it should be considered whether footprinting tools act as stand-alone "products" or as part of a wider suite of interventions and activities, which may encourage wider participation, which we feel are vital for both encouraging use of the tool and inducing change.

Conclusion

Climate change will not be avoided by technological solutions alone. Studies analyzing the drivers of increasing emission show rising demand negates any positive effect of emissions intensity gains (Baiocchi and Minx 2010). Clearly, there needs to be a radical change in consumption patterns. Bottom-up consumption-based footprint calculators, such as REAP Petite, are a potentially useful tool for end users and other stakeholders to help encourage this change in consumption behavior. This study shows that it is important to consider the design of the tool and content to ensure that the user can engage with it, and that the engagement process itself needs careful consideration to encourage tool use and behavior change.

The proliferation of indicators and footprints that result from advances in CBA have the potential to provide better information to consumers, but it is important to note that information and knowledge about the impacts of individual consumption on the society and environment, and even the motivation to shift toward more sustainable behavior, are not sufficient to cause change. Supportive infrastructure and interventions from the community to the national level are also needed to help induce and maintain behavior change.

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Supporting Information

Additional Supporting Information may be found in the online version of this article at the publisher's web site:

Supporting Information S1: This supporting information provides additional information on how the REAP Petite footprint calculator was developed. It concludes with how this tool fits within the footprinting tool landscape.